Energy flow, dynamo and field-aligned current during a substorm

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A substorm is one of the most severe disturbances that occur in the magnetosphere. Extremely bright aurora is a great manifestation of the substorm. Since the bright aurora is caused by precipitating electrons, the bright aurora is closely associated with the upward field-aligned currents (FACs). Simultaneously, a large amount of energy, of the order of 10^{11} watts, is consumed in the auroral ionosphere due to Joule dissipation during the substorm. The dissipating energy is brought by the FACs that are rapidly intensified. Thus, the formation of the FACs is a key to understand the substorm. The generation of the FACs is accompanied with conversion of energy (dynamo). The energy comes from the solar wind. The purpose of this study is to provide a unified view of a substorm in terms of the energy flow, energy conversion (dynamo) and field-aligned current on the basis of a global magnetohydrodynamics (MHD) simulation. The recent global MHD simulation tells us that, at least, some dynamo regions appear one by one in association with the substorm. The first dynamo region is found in the bow shock where the solar wind kinetic energy is converted to the magnetic energy and the internal energy. However, the role of the bow shock dynamo is suggested to be minor. The second dynamo region is found in the lobe region when the interplanetary magnetic field (IMF) is northward. A complicated structure of the plasma pressure in the lobe gives rise to the generation of FACs that could manifest high-latitude auroral arcs during the growth phase. The third dynamo region appears in the mantle region when IMF is southward. The internal energy is converted to the magnetic energy by way of the kinetic energy in the mantle dynamo. Simultaneously, a large-scale FACs (known as Region 1 FACs) are generated in association with the mantle dynamo, which is probably responsible to the formation of a quiet auroral arc during growth phase. The fourth dynamo appears in the near-Earth magnetosphere on the nightside as a consequence of the formation of the near-Earth neutral line. The magnetic energy (coming from the lobe region) is converted to the internal energy, followed by the kinetic energy and the magnetic energy. The near-Earth dynamo is associated with the onset of the sudden intensification of the upward FACs that are related to the initiation of the auroral breakup. The fifth dynamo is located near the leading/trailing edges of the bright auroral surge where charge separation takes place due to the gradient of the ionospheric Hall conductivity. A localized upward FAC is generated, which probably manifests the bright auroral surge traveling westward. It is concluded that the evolution of the substorm can be understood to the evolution of the dynamo regions in the magnetosphere and the ionosphere.

Keywords: Substorm, Energy conversion, MHD simulation

